Study of Magnetic Damping Effect on Convection and Solidification Under G-Jitter Conditions

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As shown by NASA resources dedicated to measuring residual gravity, the Space Acceleration Measurement System (SAMS) and the Orbital Acceleration Research Experiment (OARE), g-jitter is a critical issue affecting space experiments on solidification processing of materials. This ongoing study aims to provide an assessment of the use of magnetic fields in combination with microgravity to reduce the g-jitter induced flow in space. The specific objectives of this research project are threefold: (1) to determine the behavior of g-jitter induced convection in a magnetic field; (2) to assess the abilities of magnetic fields to suppress the detrimental effects of g-jitter during solidification; and, (3) to develop an experimentally verified numerical model capable of simulating transport processes and solidification phenomena under g-jitter conditions with and without a magnetic field.

An experimental setup has been built and both water and mercury are used as testing fluids. The oscillating flow, which is intended to simulate the effect of single frequency g-jitter, is generated in the fluids by applying an oscillating temperature boundary condition. A laser-based PIV system is applied to visualize and determine the oscillating convection when water is used. External magnetic fields are applied in the case of mercury and their effects on the damping of the oscillating convective flows are studied. The flow velocities in the mercury pool will be measured using hot film anemometers with and without the presence of an applied magnetic field. These experiments are intended to provide a basic understanding of the behavior of the gravity-induced oscillating convective flows with and without an applied magnetic field. Further experiments of magnetic damping during unidirectional solidification will be conducted in NASA's magnetic damping furnace at the NASA Lewis Research Center (LeRC). Both the laboratory and NASA's LeRC magnetic damping experiments will be used to verify and refine numerical models, as described below, and to assess the effectiveness of a magnetic field in damping the deleterious effects associated with g-jitter.

Analytical and numerical (2-D and 3-D) models are developed to represent the complex phenomena associated with magnetic damping during solidification in space, such as the induced Lorentz force distribution, fluid flow and temperature distribution in melts under g-jitter conditions. The analytical models are used for asymptotic behavior and order-of-magnitude estimates whereas the

numerical models provide quantitative predictions. The numerical predictions are compared with experimental measurements taken on the mercury model and on the magnetic damping furnace at NASA LeRC. The mathematical models will be refined in light of the comparison. With the experimental setups and mathematical models, the melt flow behavior under the influence of a magnetic field will be studied as a function of operating conditions for space experiments, including: (1) gravity orientation; (2) magnetic field strength; and, (3) oscillation frequency. Both steady state and transient conditions are studied. Experience gained from the physical and mathematical models will be applied to develop an integrated numerical model to determine magnetic damping effects on velocity distribution, temperature distribution, solid-liquid interface and solute distribution during solidification under g-jitter conditions.

The mathematical models described above have been applied to study the magnetic damping and g-jitter driven flows in a Bridgman-Stockbarger system for Ge-doped silicon single crystal growth in microgravity environment. Results indicate that in the absence of an applied magnetic field g-jitter driven flows can have a significant effect on mass transfer or solutal redistribution during solidification. Application of magnetic field results in damping effects on the g-jitter induced oscillating flows. With a moderate external magnetic field, the convective flows can be effectively suppressed and hence the solutal distribution becomes more uniform. The reduction of the velocity magnitude is found to be approximately inversely proportional to the applied magnetic field strength. The applied field also affects the phase angle between the g-jitter force and the oscillating convection.

Our research project addresses the application of magnetic damping to suppress the g-jitter induced flow in microgravity environment. This approach is based on extensive mathematical modeling and ground-based physical simulation and solidification experiments. Very encouraging results have been obtained so far and have helped to develop a fundamental understanding of the interactive nature of magnetic fields and transport phenomena under g-jitter conditions in microgravity. The work is being continued and the information developed from the numerical simulations and experiments will create a rational basis for the development of microgravity magnetic damping facilities for space applications. The numerical models and experimental setup will also have the potential of serving the users of magnetic damping facilities in planning experiments under microgravity conditions and interpreting the measured results obtained in space.